Q2 Known Good Substrates Technical Report
CONTRACT/PR NO. N00014-05-C-0324 Dow Corning Corporation
Quarterly Technical Report
Reporting Period: 1 June 2006 – 31 August 2006

Executive Summary

The following tables summarize progress against key milestones and metric goals after 9 months of work. The color coding shows red as incomplete milestone or below metric target, yellow as behind schedule or close to metric and green as a completed milestone or achieved metric.

KGS Program Chronological Milestones – Year 1

Thrust	Quarter	Milestone
Task 1: SiC Wafer Products	1	50% sliced wafer increase for 76 mm diameter crystals
	2	Complete model of 100 mm PVT growth*
	3	80% sliced wafer increase for 76 mm diameter crystals
	4	Deliver first generation 4H n+ 100mm wafers - DELAYED
Task 2: Materials Applied Research	1	Complete model of Generation1 bulk gas growth
	1	Qualify Batch Epitaxy processes for program
	2	Demonstration of CVT growth*
	4	Deliver first 76mm CVT wafers
Task 3: Metrology for Wafer Specifications	2	Implement LLS inspection with particles, pits, and scratches delineated.
	3	Start routine microwave loss inspection of 4H SI wafers
	2	u-PCD tool installed and lifetime measurements implemented for epitaxy layers and SI wafers
Task 4: Device Technology Maturation	1	Publish Rev-0 roadmap for wafer and epi goals
	2	Complete disposition strategy for n+ epiwafers
	4	Publish revised roadmap to reflect power and RF device progress

* Achieved Less than 45 days behind schedule

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Loboda, Mark; Carlson, Eric; Chung, Gilyong; Russell, Brian

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Dow Corning Semiconductor Solutions, LLC
2200 West Salzburg Rd, P.O. Box 994
Midland, MI 48686-0994

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9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS
Office of Naval Research
875 North Randolph St. Suite 1425
Arlington, VA 22203-1995
Attn: Collin Wood, Code : 312

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14. ABSTRACT **The Known Good Substrates (KGS) program is on track technically and financially with program tasks. Q3 wafer fabrication will be completed on time, Q3 metrology and characterization was completed, and Q2 wafers were distributed to partners early in Q3. All subcontracts are in place and many subcontractors are ramping up activities with wafers coming out of the Q1 and Q2 wafer fabrication.**

15. SUBJECT TERMS
SiC wafer, SiC epi, SiC material metrology

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			UU	**8**	**Mark Loboda**
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KGS Program Goal Metrics	Q3 2006 Status (Program Month 9)	Top 30% Goal	Top 50% Goal
Timing for 76 mm diameter	Pilot Production	Q1/06	
Timing for 100 mm diameter	100 mm wafers produced, grain boundary count below satisfactory level – 6 months behind schedule	Q1/07	
MPD and inclusions (cm^{-2})	**MPD Top 50% is <30 cm^{-2}** **MPD Top 30% is <25 cm^{-2}** **Inclusions Top 50% is <40 cm^{-2}**	<10	<30
Scratches (total length), visual inspection	Met Program goal based on Q2 final results	<50% diameter	<75% diameter
Areal density surface particles and pits in epiwafers, diameter >0.5 um	**LLS Pits <10 cm^{-2} at diameter >25um (test method not mature for <25um)**	<5 cm^{-2}	<10 cm^{-2}
Bulk Metals Contamination B, Al, Ti, V, Fe ($atoms/cm^3$)	100% is between 1E15 and 5E15	<1E15	<5E15
Stable Epi drift layer carrier concentration ($atoms/cm^3$)	100% is less than 5E14 (process development)	<1E14	<5E14
Epi thickness uniformity	100% is less than 8%	<8%	<10%
Epi Doping Uniformity	Top 60% is <15%; 20% is <10%	<10%	<15%

The program is very close to plan for milestones and metric goals. Highlights for the work performed in the third quarter show that defects have been significantly reduced. Recent changes to the PVT SiC crystal growth process have resulted in a step change in micropipe density and brought the program close to the year end objective. Improvements in polishing have significantly reduced scratching and pits as detected using laser light scattering spectrometry. Bulk metals contamination continues to stay in control below program goals.

Work on 100mm crystal growth has succeeded to produce crystals of diameter 100mm and length exceeding 25 mm, but crystal stress grain boundary density is undesirable. Recent PVT process development for 76mm diameter crystal growth has yielded new methods to reduce stress and micropipes. DCCSS feels that to achieve the desired quality for 100mm diameter crystals, it is pertinent to go stall the 100mm effort and repeat the crystal expansion work using these new techniques. Due the time required for crystal expansion, there will be a delay the delivery of 100mm wafers by an estimated 6 months.

Early work in chloride-based 76mm CVT (gas-phase bulk growth) has been very promising. Growth rates exceeding 300 um/hr have been observed. Current work has focus on operation at rates of 150-250 um/hr and layers 100-150 um thick. Growth by step flow has been observed. The layers are accurately replicating the 4H seed crystal. Micropipe closure between the seed and new crystal has been observed.

Fourth quarter efforts will focus on: initial attempts to grow 5-10mm long 76mm diameter CVT crystals; PVT work will implement new methods developed in Q3 to reduce micropipes and crystal stress on both 76mm and 100mm diameter 4H n+ crystals; finalization of LLS methods to detect small particles (diameter>1um) and improved sensitivity for pits and scratches.

Efforts are underway to schedule a milestone review meeting among all subcontractors. An interim review meeting was completed at NRL in late July. The work in the KGS program was reported in 2 papers at the 2006 ECSCRM meeting.

Technical Progress

The following table documents the key program thrusts, milestones by quarter and progress for the activity in the quarter documented by this report. New text, associated with Q3 progress is shown in black.

Thrust	Complete by Quarter	Milestone	Progress
Task 1: SiC Wafer Products	**1**	50% sliced wafer increase for 76 mm diameter crystals	Since Jan 2005 (the anticipated start of the KGS program, about which the goal was projected) the slice wafer yield has increased by 2x.
	2	Complete model of 100 mm PVT growth	Thorough modeling of 76mm was extended one month to insure agreement with all experimental results. 100 mm modeling is underway at both subcontractor and in house. Initial modeling of the heat losses has helped to drive PVT process alterations which resulted in a 3x reduction of growth rate variability in 100 mm PVT processes.
	3	80% sliced wafer increase for 76 mm diameter crystals	Since Jan 2005 (the anticipated start of the KGS program, about which the goal was projected) the slice wafer yield has increased by 2x.
	4	Deliver first generation 4H n+ 100mm wafers	Work on 100mm crystal growth has succeeded to produce crystals of diameter 100mm and length exceeding 25 mm, but crystal stress grain boundary density is undesirable. Recent PVT process development for 76mm diameter crystal growth has yielded new methods to reduce stress and micropipes. DCCSS feels that to achieve the desired quality for 100mm diameter crystals, it is pertinent to go stall the 100mm effort and repeat the crystal expansion work using these new techniques. Due the time required for crystal expansion, there will be a delay the delivery of 100mm wafers by an estimated 6 months.
Task 2: Materials	**1**	Complete model of Generation 1 bulk gas	Due to delay in release of funds for KGS, Dow Corning funds were used to initiate

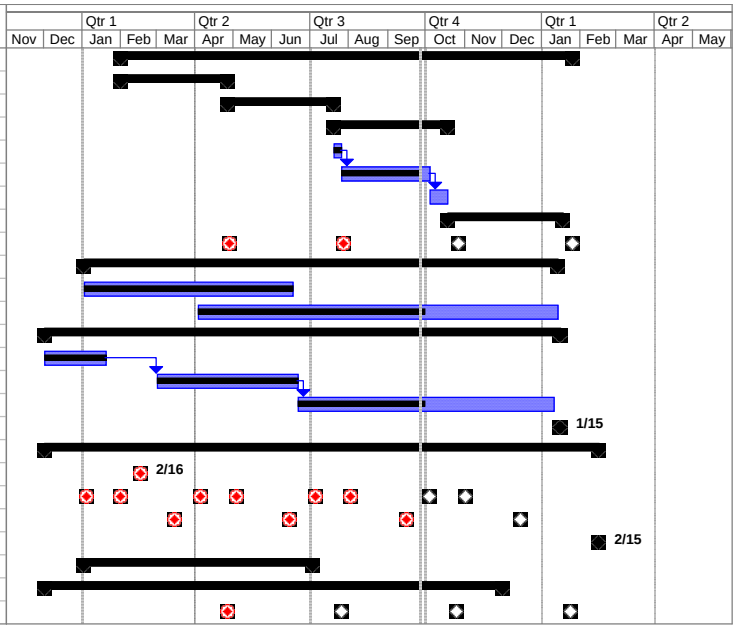
Applied Research		growth	the modeling project in the second half of 2005. A Gen-1 model has been completed based on one chlorosilane precursor and one set of process conditions. The results show that growth rate and deposition uniformity comparable to PVT processes can be expected over the temperature range 1900-2100 C. At this point it is believed largest source of error in the model is the formation of deposits on ancillary surfaces of the crucible.
	1	Qualify Batch Epitaxy processes for program	Recent epitaxy work focused to develop processes for the Northrup Grumman device subcontract. Developmental work in the multiwafer reactor produced mid doped (1E15-1E16/cm3) epi layers with thickness uniformity (standard deviation/mean) of less than 4 % and doping uniformity of less than 8%. By the end of Q2 24 epiwafers will be processed and delivered to Northrup for device fabrication. Limited work was performed to assess low doped drift layer epitaxy. In these cases it was demonstrated that levels of 5E14/cm3 could be produced in the multiwafer reactor. Epiwafer deliverables were shipped to NRL with full characterization data. Samples exhibit carrier lifetimes in the 5-10 usec range. For the remainder of the first year of the KGS program, the minimum doping target for drift layer epitaxy will stay in the 1-3E15/cm3 range to afford better assessment of carrier lifetime by microwave photoconductive decay measurement
	2	Demonstration of CVT growth	CVT (gas phase) depositions start week of 6/12/06. System is in house and facilitized.
	4	Deliver first 76mm CVT wafers	Progress in CVT growth has demonstrated rates acceptable for crystal growth on 76mm seeds. First attempts to grow crystals large enough to slice to wafers will be in October 2006.
Task 3: Metrology for Wafer Specifications	**2**	Implement LLS inspection with particles, pits, and scratches delineated.	Wafers were shipped to ONR and NRL with LLS topography maps. First generation work to segregate defect types is nearly complete and data will be provided in June. Algorithms and mapping used for pit detection and fine scratch identification are in use. The results show a clear reduction

			of pits and scratches has been achieved between Q1 and Q2. Pit and scratch levels on polished wafers are now at program goal.
	3	Start routine microwave loss inspection of 4H SI wafers	Loss measurement calibration and test is progressing well. Full wafer global loss testing in cavities has been performed at 4 GHz and compared to SI GaAs as a benchmark-Several 6H SI wafers with resistivity 1E5-1E7 ohm cm show microwave loss equal to SI GaAs. There is no obvious correlation between loss and resistivity, as expected in these materials. Mapping tests show many regions with loss less than SI GaAs. Next focus is on extending the measurements to X-band. In Q3 a method for measurements of microwave loss on SiC wafers has been developed. Trends closely mimic the observations at L-Band. In general, the results show that SiC is a lower loss material than both GaAs and alumina.
	2	u-PCD tool installed and lifetime measurements implemented for epitaxy layers and SI wafers	u-PCD testing of carrier lifetime is fully operational. Key results show that chlorosilane-based SiC epi has very high lifetime. Samples were delivered to NRL for conformational analysis. Photoluminescence decay tests at NRL confirm long recombination lifetime values in chlorosilane-based epitaxial layers grown and tested at Dow Corning. The samples generated to date in the KGS program represent the longest lifetime values reported in the literature. Efforts at ASU to measure generation lifetime in MOS structures grown on chlorosilane-based epitaxial layers also show large values consistent with PL and u-PCD testing. A provisional patent has been filed by Dow Corning regarding gas phase processes to produce long lifetimes in SiC semiconductors.
Task 4: Device Technology Maturation	**1**	Publish Rev-0 roadmap for wafer and epi goals	See Appendix 2
	2	Complete disposition strategy for n+ epiwafers	See Appendix 3.
	4	Publish revised roadmap to reflect power and RF device progress	

Schedule

A detailed description of achievements and progress against milestones and deliverables was provided in the table above. The project schedule is provided below as an overview of the progress against the high level tasks on the program. Progress is on track with exception of the gas phase (CVT) task, which is 1.5 months behind due to delays at the tool vendor (the schedule has been update accordingly) and the 100mm wafer task (described in the technical section above).

ID	Task Name
1	**SiC Boule Growth & Wafer Fabrication**
2	**Q1 Cycle**
6	**Q2 Cycle**
10	**Q3 Cycle**
11	Pareto Analysis/Set Boule Targets
12	Wafer Processing
13	Data Analysis
14	**Q4 Cycle**
18	**Quarterly Wafer Deliverable**
23	**Epi Development**
24	Qualify Batch Epitaxial Process
25	Perform Epi Growths
26	**CVT Development**
27	CVT Process Modeling
28	Furnace Conversion
29	CVT Process Development
30	CVT Grown 3" Boule
31	**Program Management**
32	Kickoff Mtg
33	**Monthly Status Report**
42	**Quarterly Reports**
47	Final Report
48	**Subcontract Agreements**
57	**Material Purchases**
63	**Quarterly Meetings**



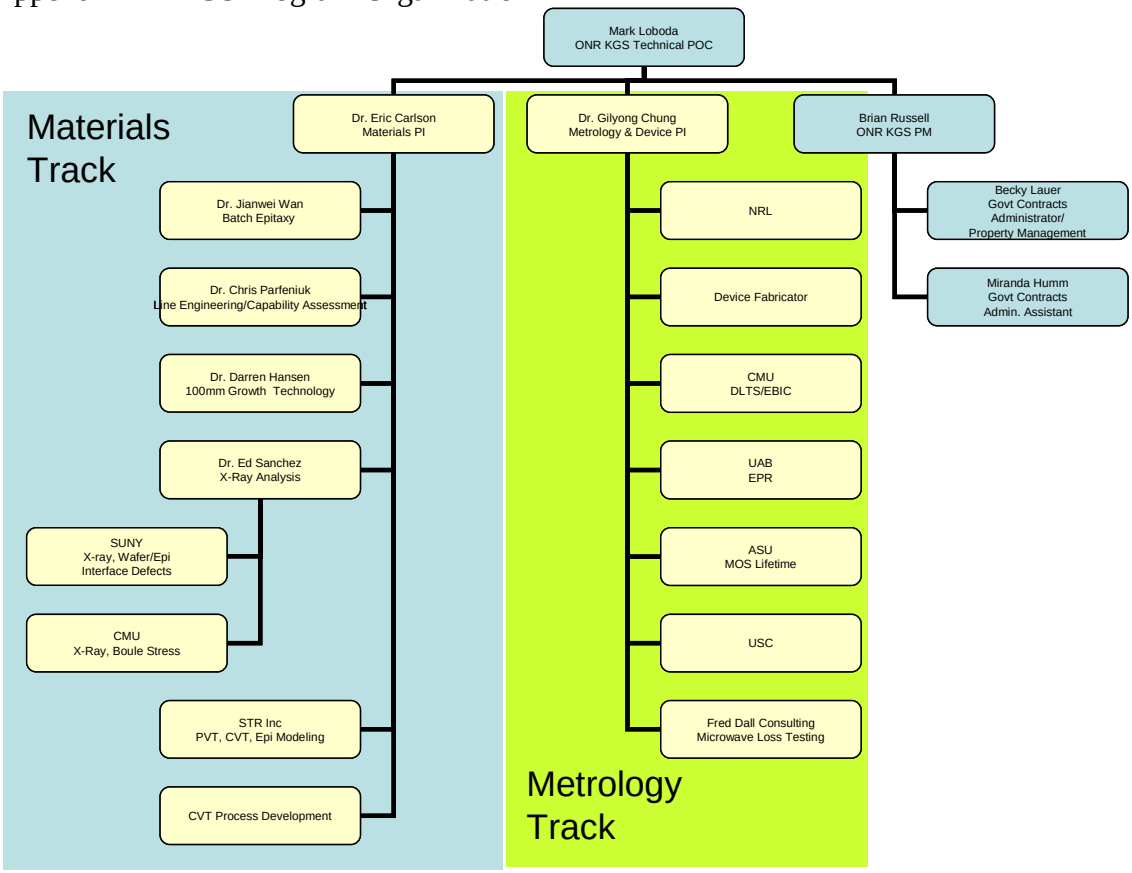
Program Management

Monthly e-mail status updates were submitted to the Program Officer, Dr. Colin Wood. The face to face (all participants) program review meeting that was planned for October has been moved to December due to scheduling conflicts for a majority of the attendees in the months of October and November. All subcontract agreements have completed negotiations. Appendix 3 contains the updated distribution of program wafers. It is important to note that the original plan had to be modified to meet various needs and opportunities for the work on the program – see Appendix 3 for details.

Cost Status

Cost status updates are provided to Dr. Colin Wood in the monthly e-mail updates.

Appendix 1 – KGS Program Organization



Appendix 2 – KGS Rev-0 Roadmap for Wafer and Epi Goals

Proposed Goals:	Top 30%	Top 50%
Timing for 76 mm diameter	Q1/06	
Timing for 100 mm diameter	Q1/07	
MPD and inclusions (cm^{-2})	<10	<30
Scratches (total length)	<50% diameter	<75% diameter
Areal density surface particles and pits in epiwafers, diameter >0.5 um	<5 cm^{-2}	<10 cm^{-2}
Bulk Metals Contamination B, Al, Ti, V, Fe ($atoms/cm^3$)	<1E15	<5E15
Stable Epi drift layer carrier concentration ($atoms/cm^3$)	<1E14	<5E14
Epi thickness uniformity	<8%	<10%
Epi Doping Uniformity	<10%	<15%

Appendix 3 – KGS Wafer Disposition Plan

Wafers Produced for Program	Q1	Q2	Q3	Q4	Total Wafers
75mm n+	0	43	21	28	92
75mm SI	0	0	6	8	14
100mm n+	0	0	3	4	7
100mm SI	0	0	0	2	2
Total	0	43	30	42	**115**

	Epi	No Epi	Epi	No Epi	Epi	No Epi	Epi	No Epi	total epi Wafers	Epi Growths
Internal 3" Epi n+			37	6	21		26	2	84	16.8
Internal 3" Epi SI						6		8	0	0
Internal 4" Epi n+						3	2	2	2	2
Internal 4" Epi SI								2	0	0

Distribution	Epi	No Epi	Epi	No Epi	Epi	No Epi	Epi	No Epi	
NRL (Lifetime Measurements)			5		2	2	4	2	15
CMU (Deep Level, XRT)					2	2	2	3	9
Alabama (Deep Level Measurements)						2		3	5
ASU (Lifetime Measurements)					2		2		4
USC (Diodes)			2		1		1		4
NGES			28		14		14		56
ONR			2	6		3	5	6	22
									115

Mixed Lots
n+
SI

The plan is slightly altered from that in the original proposal. No cost changes result. The number of wafers increases. Changes are primarily a result of the Northrup Grumman subcontract which required more n+ wafers than originally proposed. To accommodate this less semi-insulating material will be produced. DCCS has already started to send in deliverables shown in the Q2 part of the plan. Additional wafers were sent to University of Alabama, Arizona State and CMU at no cost to the program.